A MEASUREMENT TECHNIQUE TO IMPROVE QUALITY CHARACTERISTICS IN INDUSTRIAL PROCESSES

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Abstract − In industrial field, one of the most advantages, derived from the industrial automation process implementation, is possibility to regulate process control parameters. It allows parametric optimisation methodologies application.

In the paper an innovative methodology for the productive processes qualification based on quality characteristics improvement and on their simultaneous evaluation cost, is proposed.

An industrial farm (Leghe Leggere spa) application of the proposed technique is discussed.

Keywords : Parametric Optimisation, Experimental Design, Quality.

1. THE PROPOSED APPROACH

Parametrical optimisation techniques, based on traditional SPC tools, are generally implemented through an experimental design to find control parameters combination that give the optimum value of the quality characteristic selected, normally expressed from the decibel ratio signal/noise.

Innovative author's approach, here proposed, is to combine the efficaciousness of the described techniques with an appropriate analysis of all global cost factors considering both control parameter combination, pre and post-optimisation.

The costs, related to the improvement activities on the quality characteristic selected, are evaluated through a Quality Loss Function:

$$L(y) = \frac{A_o}{\Delta_o^2}(y - m)^2 \tag{1}$$

in which $\frac{A_o}{\Delta_o^2}$, generally indicated with "K", is constant defined as quality cost coefficient, whose determination is conducted fixing the tolerance limit behind output product is reworked and evaluating the relative cost through a complex analysis of all economic impact factors (people, energy use, devaluation).

The expression (1) has to be applied in the two operative conditions, pre and post experimentation, to verify the presence of an increment of cost function. In fact, certainly the quantity $(y-m)2$ is reduced after the experimentation, as imposed, but the coefficient K value should be incremented according to new distribution of the economic impact factors.

Proposed methodology application allows the industrial processes quality characteristic optimisation, through the choice of the control parameters opportune parametrical combination that make system insensible to noise factors, and through the analysis of the cost function.

The methodology structure based on the typical application step by step allows its implementation according to iterative approach PDCA (Plan Do Check Control Act).

2. CASE STUDY

Here the results of the application of the proposed methodology to industrial farm (Leghe Leggere spa) are reported.

Quality characteristic selected is superficial hardness of the aluminium bar produced in the farm analyzed.

To verify the goodness of the measurement process, data are distributed in classes and, for each class are evalueted the absolute, relative and cumulative frequencies.

Starting from the evaluated frequencies, a normality test is been conducted, through the χ^2 TEST based on the comparison between the value found through the expression (2) and relative to the observed data and the statistical value χ^2 of the distibution reported in Literature.

$$\chi^2_{k-p-1} = \sum \frac{(F_0 - F_t)^2}{F_t} \tag{2}$$

where:

1 F_0 = observed frequencies
2 F_t = theoretical frequencies
3 k = classes number
4 p = parameters number

It has been possible to accept normality Hypothesis with significant level of 0,01 %, id est, a confidence interval of 99,99%.

Ones the normality of measurement process is verified, the proposed approach provides the control parameter definition.

In the dealt case control paramter selected, and their levels are reported in tab. I.

The first one is the % of aluminium bar components. The others ones are relative, respectively, to the oven remaining time, to the oven temperature and to the oven waiting time.
For each one have been defined tree levels to measure process curvature.

TABLE I. Control Parameters

Levels	$\dfrac{Mg}{Si}$	t_a (h)	T (C°)	T_p (h)
1	$\dfrac{Mg}{Si} = 0,90$ Mg=0,38 % Si=0,42 %	16	175	8
2	$\dfrac{Mg}{Si} = 1,09$ Mg=0,48% Si=0,44%	14	185	6
3	$\dfrac{Mg}{Si} = 1,21$ Mg=0,58 % Si=0,48 %	12	200	4

For the parametrical optimization with 4 control parameters and 3 levels, it has been chosen the L9 orthogonal matrix reported in Literature, shown in tab. II

TABLE II. Orthogonal matrix L9

Col. N.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

In the dealt case, target value of the quality characteristic is a limited nominal value (70 Brinnel) and it has satisfy the condition to be included in the interval 60-80 Brinell, than a signed-target objective function, reported in Literature is been chosen:

$$\eta = -10\log\sigma^2 \qquad (3)$$

According to the orthogonal matrix considered, 9 experiments have been conducted and for each one have been tested five aluminium bars, in tree different point as shown in tab. III, where average and variance calculated are reported.

TABLE III. Measured Data

Experiment	Top	Middle	Bottom
1	76±1	73±2	76±1
2	73±1	73±1	75±2
3	68±1	70±1	72±1
4	85±3	83±2	78±3
5	73±1	80±1	80±1
6	69±3	62±3	64±1
7	84±1	78±1	78±2
8	80±2	85±3	80±2
9	85±1	85±1	80±3

For each of 9 experiments average variance are evalueted:
From calculation of σ results:

$$\sigma_1^2 = \frac{1}{3}\left(6^2 + 3^2 + 6^2\right) = 27,00$$

$$\sigma_2^2 = \frac{1}{3}\left(3^2 + 3^2 + 5^2\right) = 14,33$$

$$\sigma_3^2 = \frac{1}{3}\left[\left(-2\right)^2 + 0 + 2^2\right] = 2,67$$

$$\sigma_4^2 = \frac{1}{3}\left(15^2 + 13^2 + 8^2\right) = 152,67$$

$$\sigma_5^2 = \frac{1}{3}\left(3^2 + 10^2 + 10^2\right) = 69,67$$

$$\sigma_6^2 = \frac{1}{3}\left[\left(-1\right)^2 + \left(-8\right)^2 + \left(-6\right)^2\right] = 33,67$$

$$\sigma_7^2 = \frac{1}{3}\left(14^2 + 8^2 + 8^2\right) = 108,00$$

$$\sigma_8^2 = \frac{1}{3}\left(10^2 + 15^2 + 10^2\right) = 141,67$$

$$\sigma_9^2 = \frac{1}{3}\left(15^2 + 15^2 + 10^2\right) = 183.33$$

(4)

than for the objective function selected results:

TABLE IV. Experimental results of orthogonal matrix.

Experimental number	$\dfrac{Mg}{Si}$ (A) [%]	Oven remaining time (B) [hours]	Oven temperature (C) [°C]	Oven waiting time (D) [hours]	η [dB]
1	0,90	8	175	16	-14,31
2	0,90	6	185	14	-11,56
3	0,90	4	200	12	-4,27
4	1,1	8	185	12	-21,82
5	1,1	6	200	16	-18,43
6	1,1	4	175	14	-15,27
7	1,2	8	200	14	-20,33
8	1,2	6	175	12	-21,51
9	1,2	4	185	16	-22,63

Analysis is conducted with hypothesis of independence of control parameters and for each level results,

$$\overline{A_1} = \frac{-14,31 - 11,56 - 4,27}{3} = -10,05 \qquad (5)$$

$$\overline{A_2} = \frac{-21,82 - 18,43 - 15,27}{3} = -18,51$$

$$\overline{A_3} = \frac{-20,33 - 21,51 - 22,63}{3} = -21,49$$

$$\overline{B_1} = \frac{-14,31 - 21,82 - 20,33}{3} = -18,82$$

$$\overline{B_2} = \frac{-11,56 - 18,43 - 21,51}{3} = -17,17$$

$$\overline{B_3} = \frac{-4,27 - 15,27 - 22,63}{3} = -14,06$$

$$\overline{C_1} = \frac{-14,31 - 15,27 - 21,51}{3} = -17,03$$

$$\overline{C_2} = \frac{-11,56 - 21,82 - 22,63}{3} = -18,67$$

$$\overline{C_3} = \frac{-4,27 - 18,43 - 20,33}{3} = -14,34$$

$$\overline{D_1} = \frac{-14,31 - 18,43 - 22,63}{3} = -18,46$$

$$\overline{D_2} = \frac{-11,56 - 15,27 - 20,33}{3} = -15,72$$

$$\overline{D_3} = \frac{-4,27 - 21,83 - 21,51}{3} = -15,77$$

Than is possible to reach the optimum configuration of control parameters to maximize the objective function, as shown in tab.V.

TABLE V. Parameters levels optimum choice

Variable	Parameter	Optimum level
A	$\dfrac{Mg}{Si}$	0,90
B	Oven remaining time	4 h
C	Oven temperature	200°C
D	Oven waiting time	14 h

Than methodology application follows with an Analysis of Variance (*ANOVA*) to determine the effects of each control parameter on the quality characteristic variation.

Total variation SS_t (Total Sum Square) can be divided in its five components:
SS_A variation owned to factor A
SS_B variation owned to factor B
SS_C variation owned to factor C
SS_D variation owned to factor D
SS_e variation owned to error

$$SS_T = SS_A + SS_B + SS_C + SS_D + SS_e \qquad (6)$$

$$SS_T = [\sum_{i=1}^{N} \eta_i^2] - \frac{T^2}{N} \qquad (7)$$

$SS_T = 290,03$

$$SS_V = \frac{V_1^2}{n_{V_1}} + \frac{V_2^2}{n_{V_2}} + \frac{V_3^2}{n_{V_3}} - \frac{T^2}{N} \qquad (8)$$

with V = A, B, C, D
Main effects of control parameters are shown in tab.VI

TABLE VI. Main effects

	A	B	C	D
1	-30,14	-56,46	-51,09	-55,37
2	-55,52	-51,50	-56,01	-47,16
3	-64,47	-42,17	-43,03	-47,60
TOTAL	-150,13	-150,13	-150,13	-150,13

$SS_A = 211,42; \; SS_B = 35,09; \; SS_C = 28,62; \; SS_D = 14,21$

$SS_e = SS_A + SS_B + SS_C + SS_D - SS_T = 0,68$

Comparison between the effects of each control parametr and the error on the quality characteristic variation is been performed through Fisher test, in which the ratio between the evaluated variance of each factor and the error one, is compared with the the statistical value F of the Fisher distibution reported in Literature Fischer test results are shown in table VII:

TABLE VII. Fischer Results

Source	Variation (SS)	DoF	Variance	F
A	211,42	2	105,71	459,70
B	35,09	2	17,54	76,26
C	28,63	2	14,32	62,26
D	14,21	2	7,10	30,86
e	0,68	3	0,23	
T	290,03	11		

From the table results that quality characteristic variation is owned to parameter variation and not to the error, and above all it depends from factor A variation. In the last step of the application, the costs, related to the improvement activities on the quality characteristic selected, are evaluated through Quality Loss Function:

$$L(y) = \frac{A_o}{\Delta_o^2}(y - m)^2 \qquad (9)$$

$$k = \frac{A_0}{\Delta_0^2} = \frac{0,71}{10^2} = 0,0071 \qquad (10)$$

in which $\Delta o=10$ for the imposed condition for the superficial hardness to be included in 60-80 Brinnel interval with 70 Brinnel as nominal value.
Ao=0,71€kg has been evaluated through a global analysis of economic impact factor, people work, energy consume and administrative services.
From the executed experimentation results that the optimum combination of control parameters that maximize the objective function η is $A_1 B_3 C_3 D_2$.

Than, in these conditions, the average objective function(dB expressed) μ results:

$$\mu = \overline{A_1} + \overline{B_3} + \overline{C_3} + \overline{D_2} - 3\overline{T} = -4,13 \qquad (11)$$

and:

$$-10 \log \sigma^2 = -4,13 \Rightarrow \sigma^2 = 2,59$$

In this case, the proposed technique has produced a strong improvement of the quality characteristic selected (superficial hardness of aluminium bar) and contemporary has produced a reduction of associate productive unitary cost through the preliminary check of the critical productive phases in term of energy use. For example, considering only the quality loss owned to variation, results:

$$L_d = k\sigma^2 = 0,02\left[\frac{\text{€}}{kg}\right] \qquad (12)$$

Pre–experimentation control parameter combination was A_1, B_2, C_2 e D_2, characterized by μ :

$$\mu = \overline{A_1} + \overline{B_2} + \overline{C_2} + \overline{D_2} - 3\overline{T} = -11,57 \qquad (13)$$

and:

$$-10 \log \sigma^2 = -11,57 \Rightarrow \sigma^2 = 15,35$$

than the pre-experimentation value of quality Loss was:

$$L_p = k\sigma^2 = 0,11\left[\frac{\text{€}}{kg}\right] \qquad (14)$$

from (12) and (14), after experimentation results a average economic improvement of:

$$L_p - L_d = 0,11 - 0,02 = 0,08\left[\frac{\text{€}}{kg}\right] \qquad (15)$$

Behind, after the methodology application, results a reduction of the average methane consume in the oven cycle, shown in fig. 1. The optimum parametrical combination derived from the proposed application is been able to reduce the K coefficient in the constant temperature phase, more than the increment it had registered in the transitory phases. In fact observing the factor B and C, the first one, from the pre (fixed at second level) to post-experimentation (changed at third level), reduce itself, while the second one from the pre (fixed at second level) to post-experimentation (changed at third level), grows, and the reduction of the one is greater than the growth of the other with an
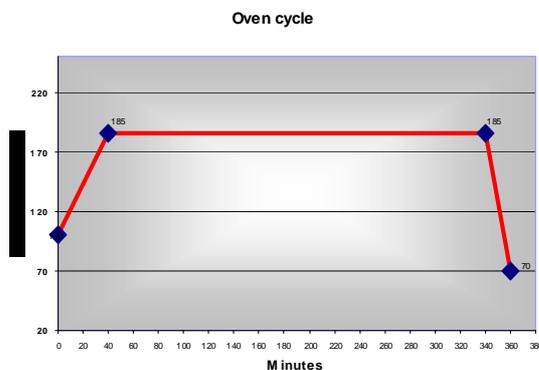
Oven cycle

Fig.1 Oven cycle
associate total reduction of methane consume.

3. CONCLUSION

In the paper a innovative methodology for the productive processes qualification based on quality characteristics improvement and on their simultaneous evaluation cost, is proposed

The proposed approach is applicable to every type of productive processes after giving them a p-diagram structure as described. Its innovative idea to optimize quality characteristics through an objective function and contemporary minimize the related cost function allows compatible industrial farm strategy improvements.

REFERENCES

[1] ISO 9001: Quality Systems-Model for Quality Assurance in Design, Development, Production, Installation and Servicing.

[2] Suri R. (1999). An Integrated System Model for Reducing Variation in Manufacturing Systems. Mechanical Engineering. Cambridge, MA, Massachusetts Institute of Technology: 140.

[3] Suri R. and Otto K. (1998). Concurrent Part and Process Design for Quality Improvement. ASME Design for Manufacturing, Atlanta, ASME.

[4] Frey D. and Otto K. (1996). The Process Capability Matrix: A Tool for Manufacturing Variation Analysis at the Systems Level. ASME Design Theory and Methodology Conference, 1997, Sacramento, CA.

[5] Frey D., Otto K., et al. (1997). "Manufacturing Block Diagrams and Optimal Adjustment Procedures." Submitted to ASME Journal of Manufacturing Science and Engineering.

[6] De Capua C., Malafronte G.C., Polese N., 'Measurement Uncertainty Analysis in Process Monitoring', 8° International Congress of SIGEF (pp.237-242), Naples 2001.

[7] De Capua C., Landi C., Malafronte G.C., Measurement of Quality Indexes in Process Monitoring: An Original Approach to Uncertainty Analysis, XVII IMEKO World Congress, June 2003, Dubrovnik.

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